1550 nm Tunable Lasers and VCSEL Arrays for WDM applications

L. A. Coldren
UC-Santa Barbara

- Increase bandwidth without increasing data rate/electronics' performance
- Parallel protection channels in one medium (cost/size/weight/robustness)
- Wavelength selective routing (very fast, efficient, and remote routing)
- Outstanding leverage in commercial marketplace (but it isn't addressing important issues)
- Need small, fast, efficient, chip-scale O/E components

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Outline
(1550 nm InP-based hardware)

- SGDBR Widely-tunable Lasers/Laser-Modulators/Laser-Amplifiers

  -- Needed: Compact/efficient wavelength converter/SGDBR
  Compact/efficient wavelength router
  Integration/packaging

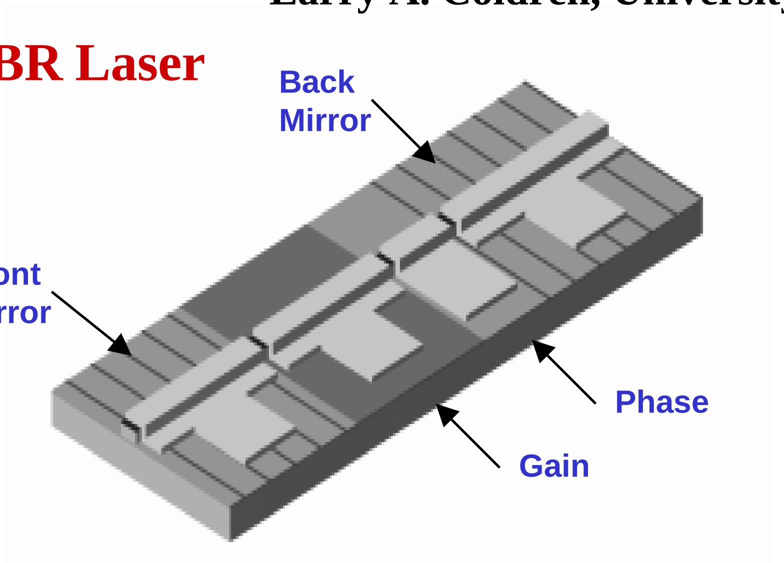
- 1550nm VCSELs

  -- Needed: Higher performance/better manufacturability
  WDM arrays/coupling optics
  Amplifiers/wavelength converters

Improved Sampled Grating DBR Widely-Tunable 1.55µm Lasers

Larry A. Coldren, University of California Santa Barbara

SGDBR Laser



Objective

•Improved widely tunable SGDBR laser
•Increase tuning range to greater than 60nm
•Develop integrated wavelength monitor for tuning control
•Develop integrated modulator & amplifier designs

Approach

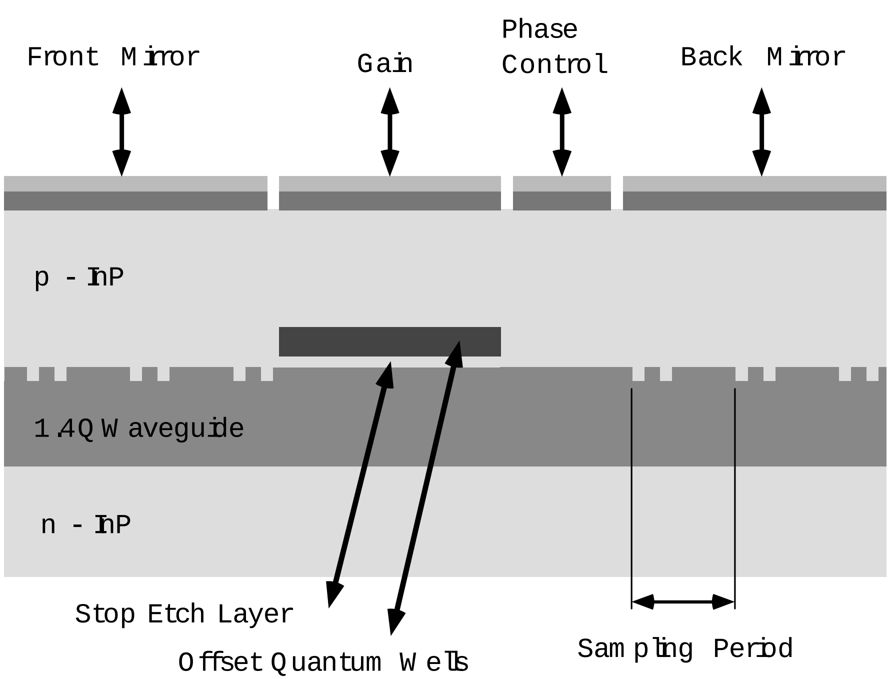
•Dry etch gratings through windows in SiNx mask for improved regrowth
•Employ a thick low bandgap waveguide to increase index tuning efficiency
•Taper the active passive junctions to eliminate spurious reflections
•Employ a buried heterostructure design for improved carrier confinement

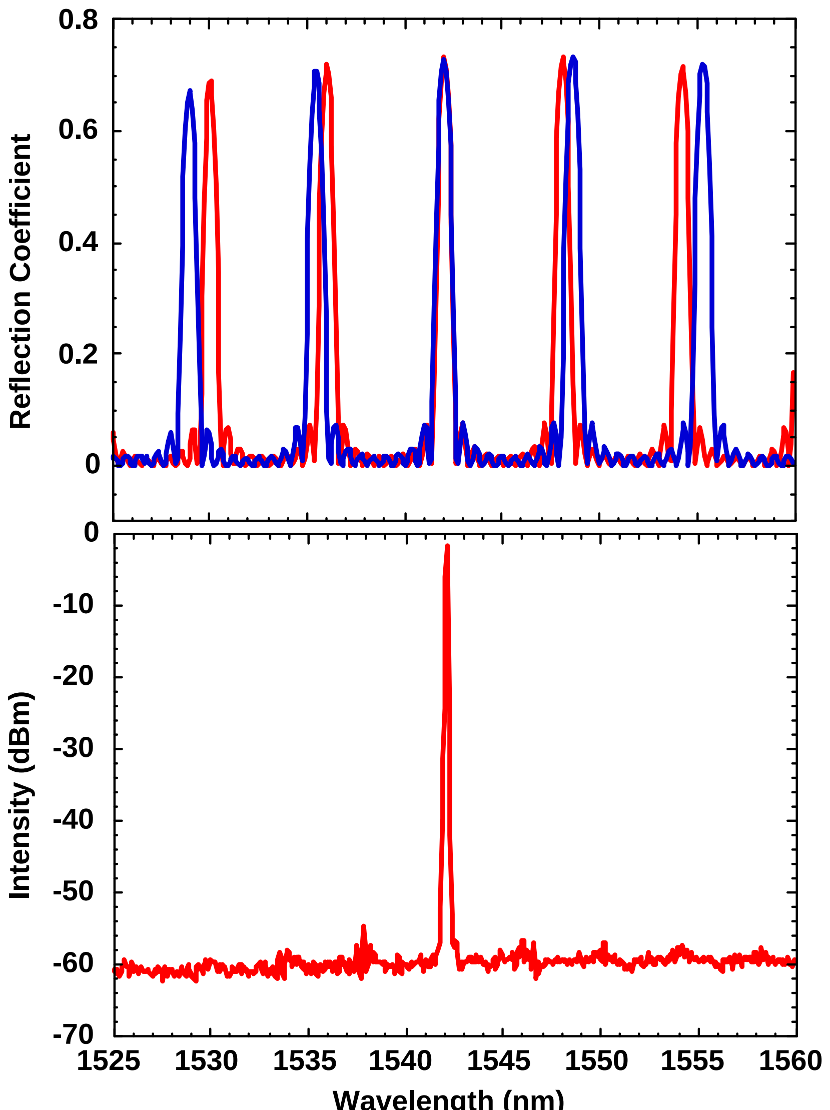
Accomplishments

•Demonstrated continuous tuning range of 72 nm for buried device
•Developed integrated wavelength monitor
•Integrated the tunable laser with an electro-absorption modulator capable of 22dB extinction over a 47nm tuning range
•Integrated a SOA with a gain of 8.5dB and a 6mW saturation power together with the SGDBR
•Transferred technology to Agility Communications

Introduction SGDBR Lasers

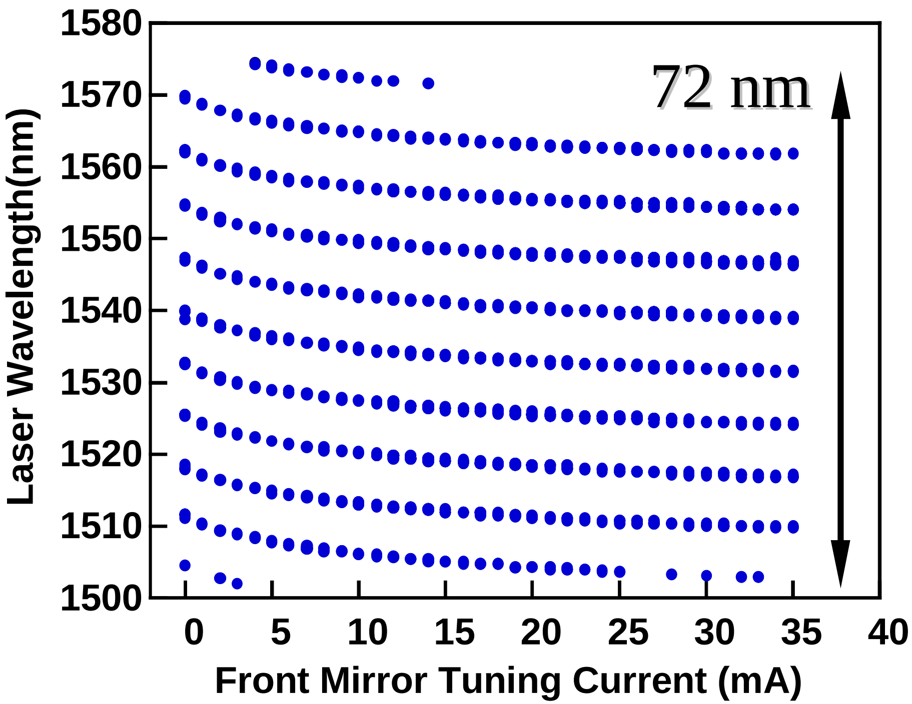
- Periodically sampling the gratings in the mirrors yields multiple reflection peaks.
- The laser wavelength is controlled by aligning reflection peaks in the front and back mirrors.

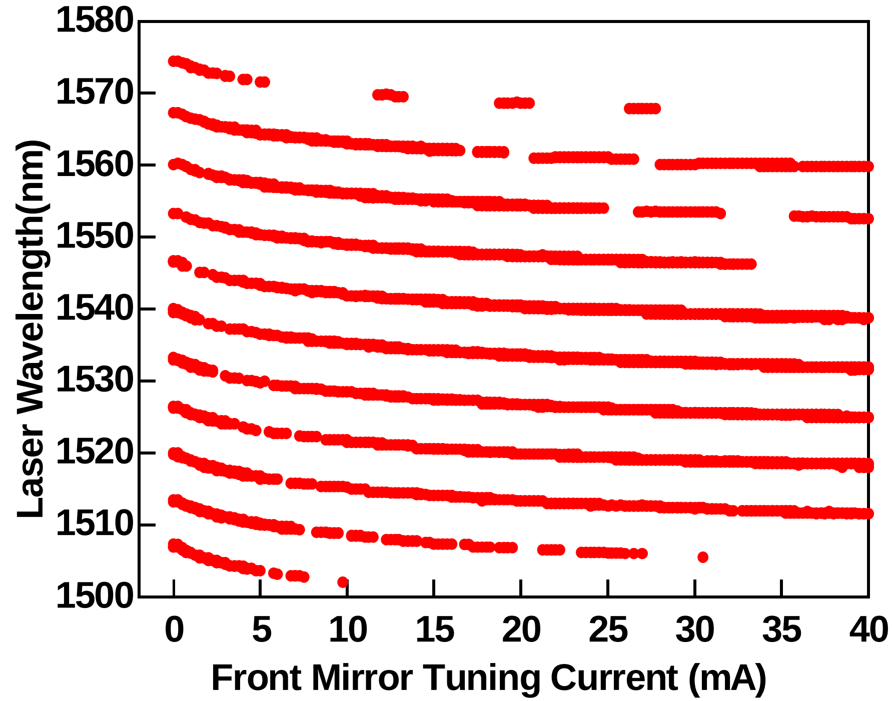




UCSB

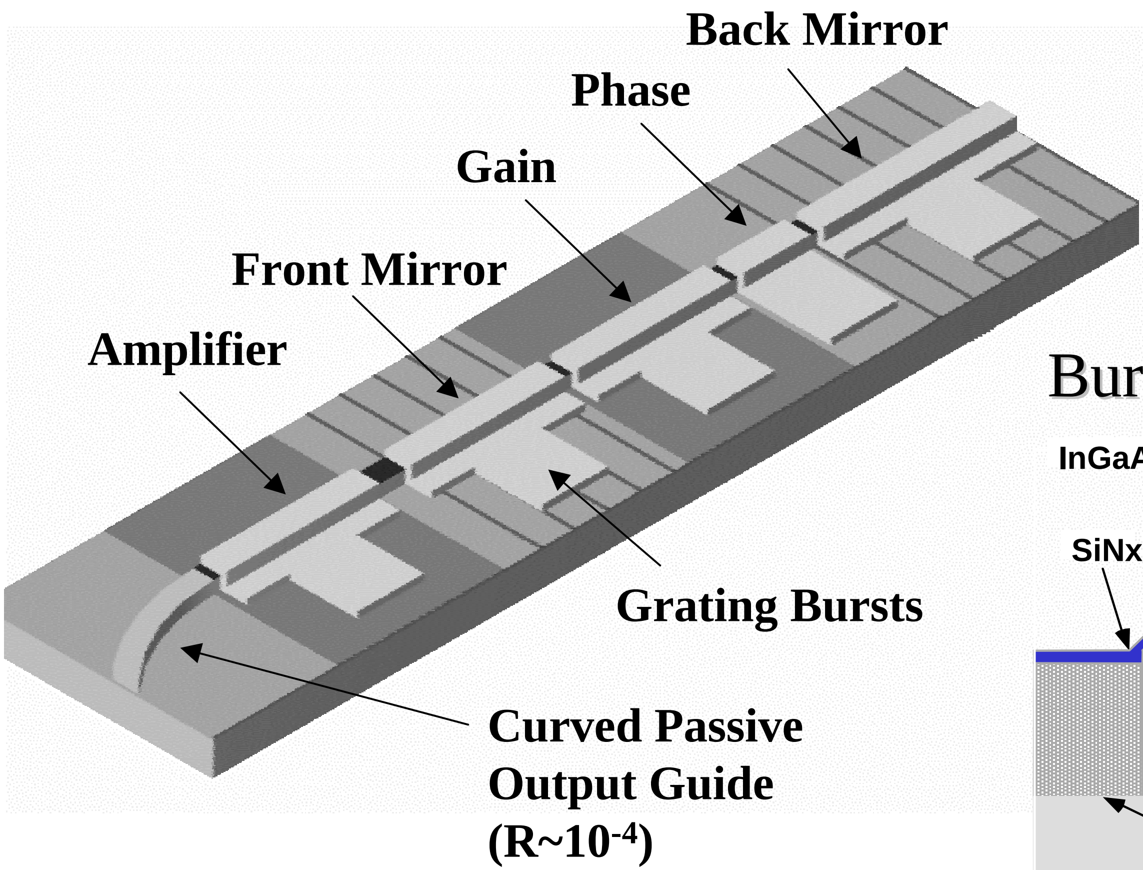
72 nm Quasi-Continuous Tuning Range

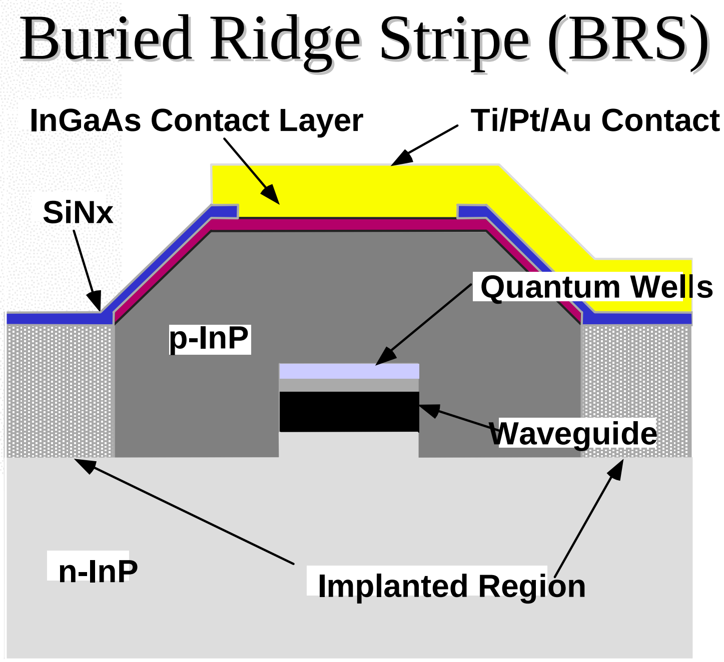




- 180 50 GHz channels, > 35 dB SMSR, 2 mW peak power
- Tuning range limited by available gain from MQW.

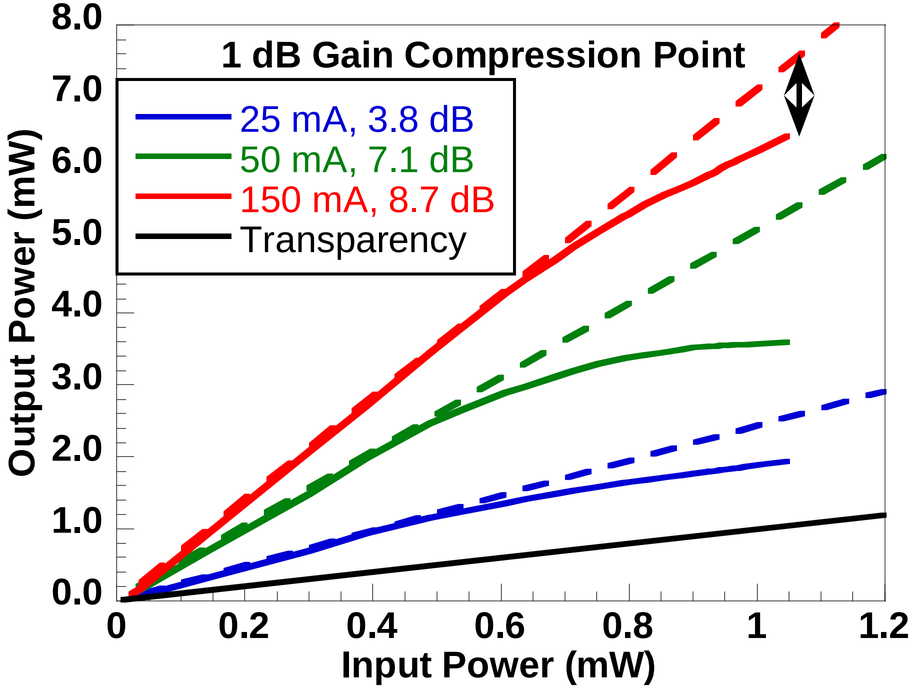
Integrated SGDBR and SOA Device Structure

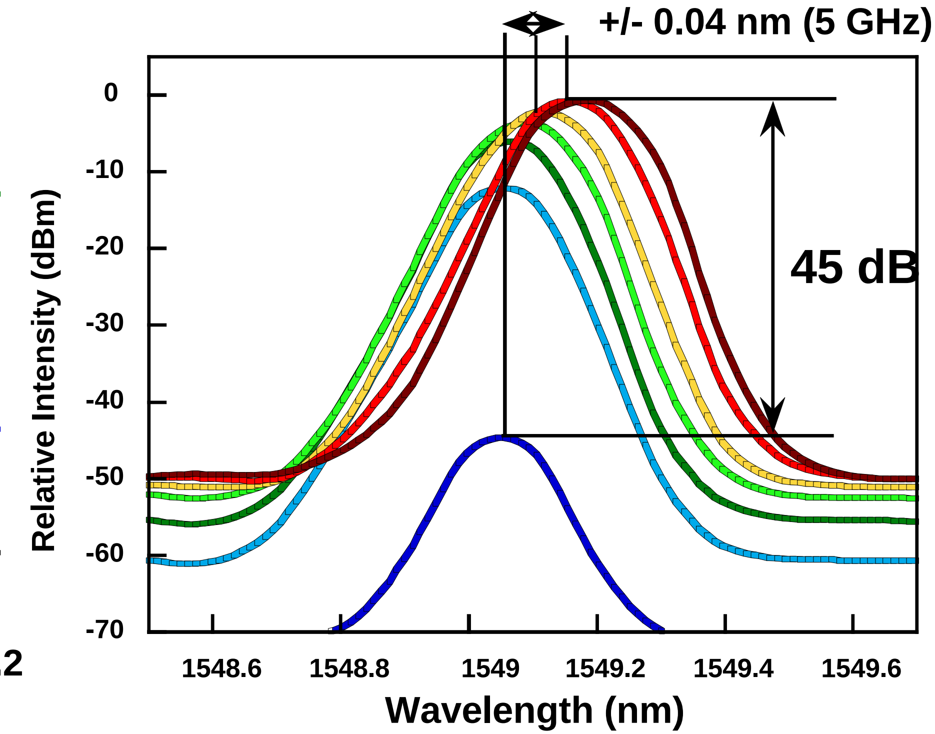




- Waveguide: 1.4 µm InGaAsP
- Active Region: Six 1% Compressively Strained QWs

Integrated Amplifier Characteristics

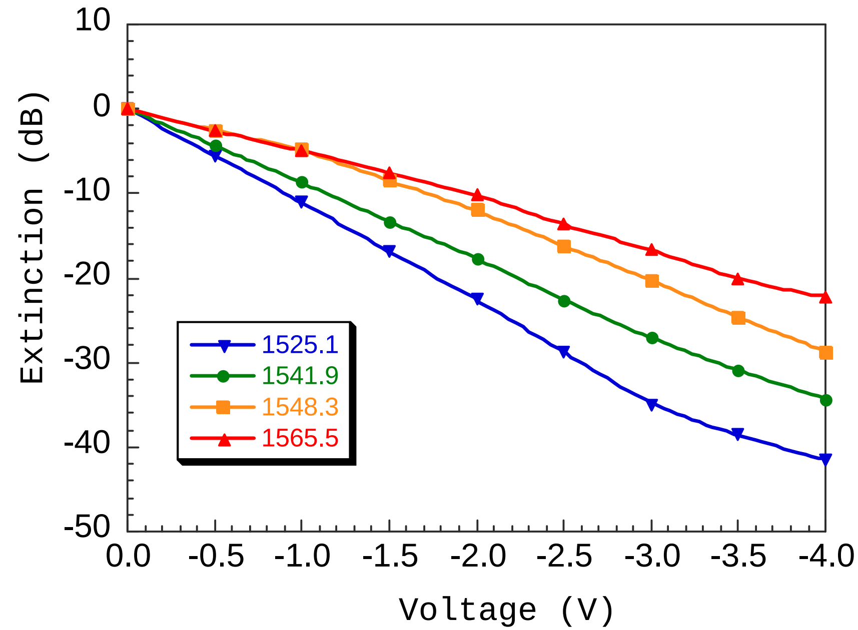


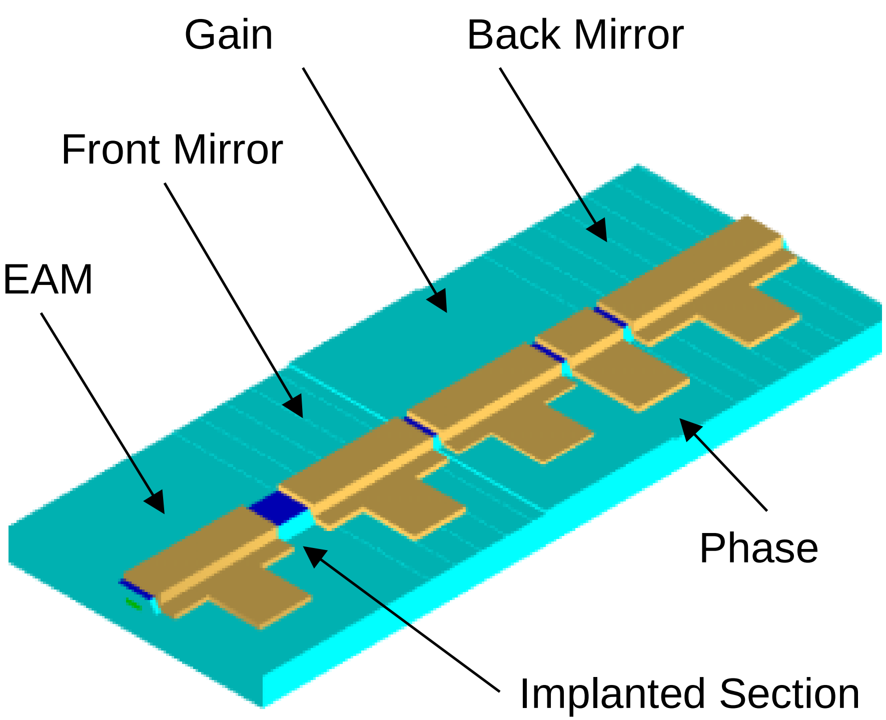


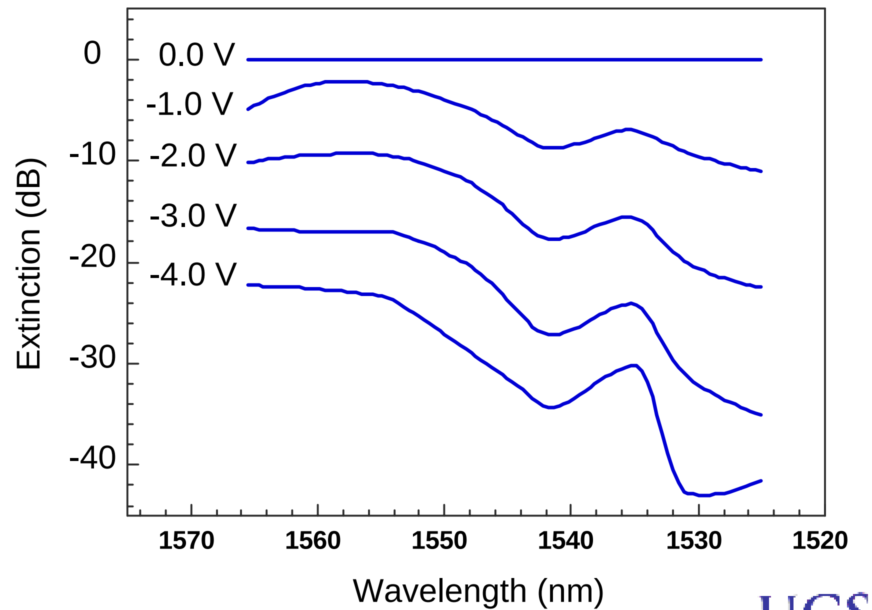
- 6 mW peak output power (1 mW min) , 8.5 dB gain.
- <10 GHz wavelength shift with 45 dB power variation.

SGDBR Lasers With Integrated Electro-Absorption Modulators

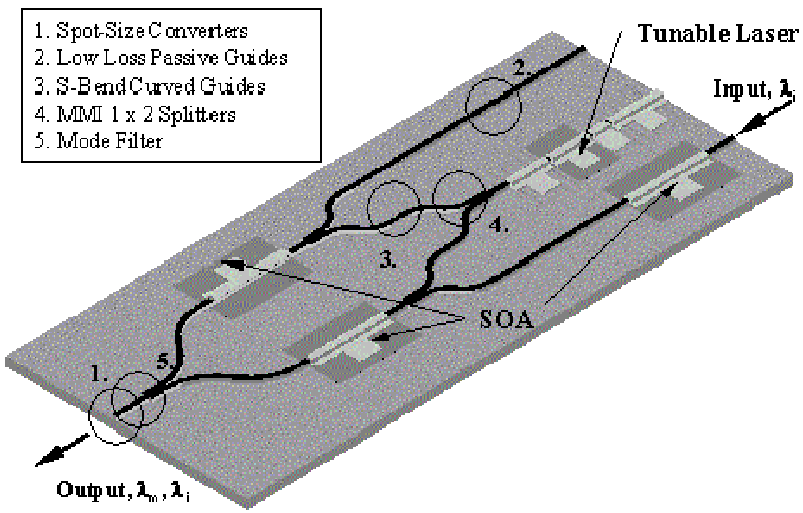
- Extinction Ratio is Greater Than 22 dB over the entire 40 nm tuning range of the laser for a 250 μm long modulator.

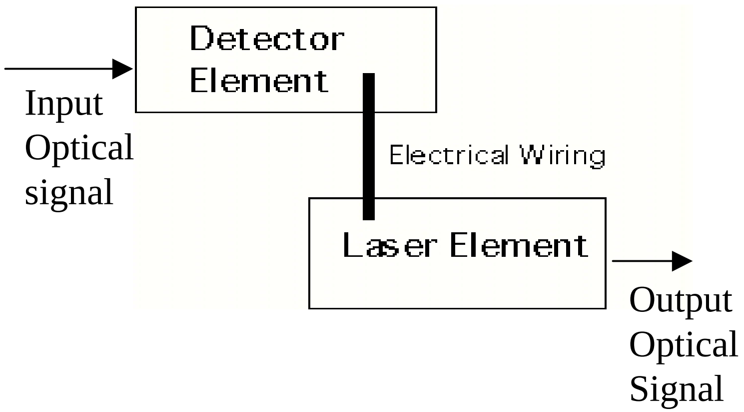






Wavelength Converter types





All-optical λ-converter:

-Uses interferometric branches

- Signal remains optical

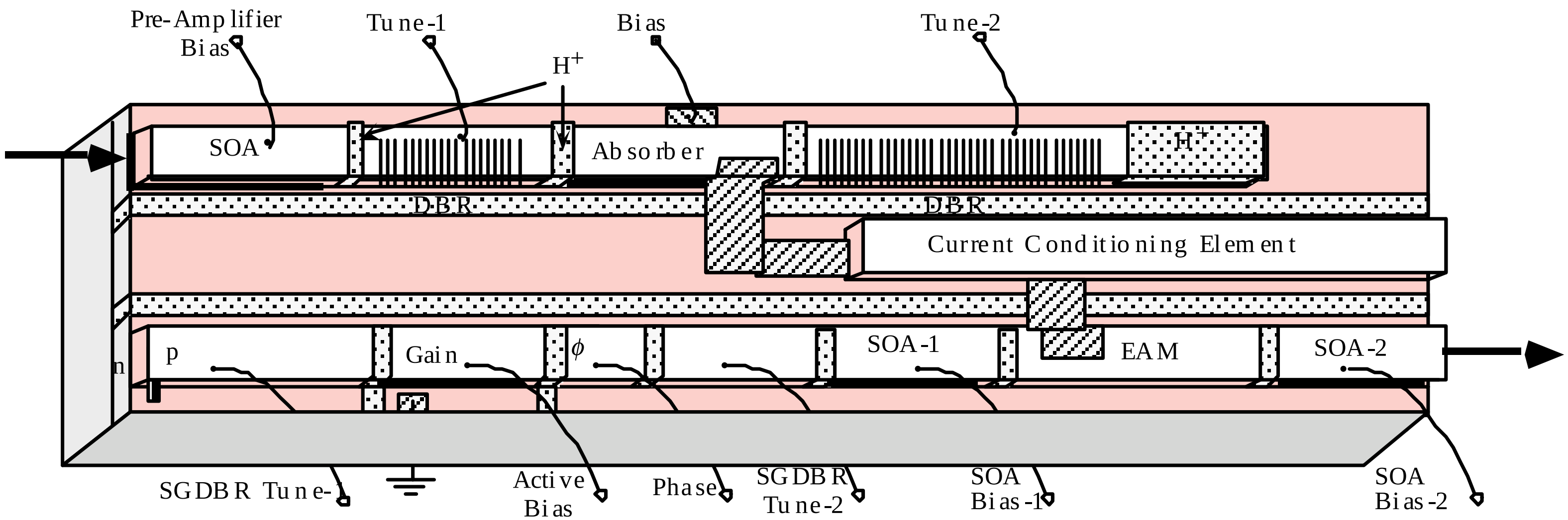
- Design more complex

- Physically large device

Opto-Electronic λ-converter:

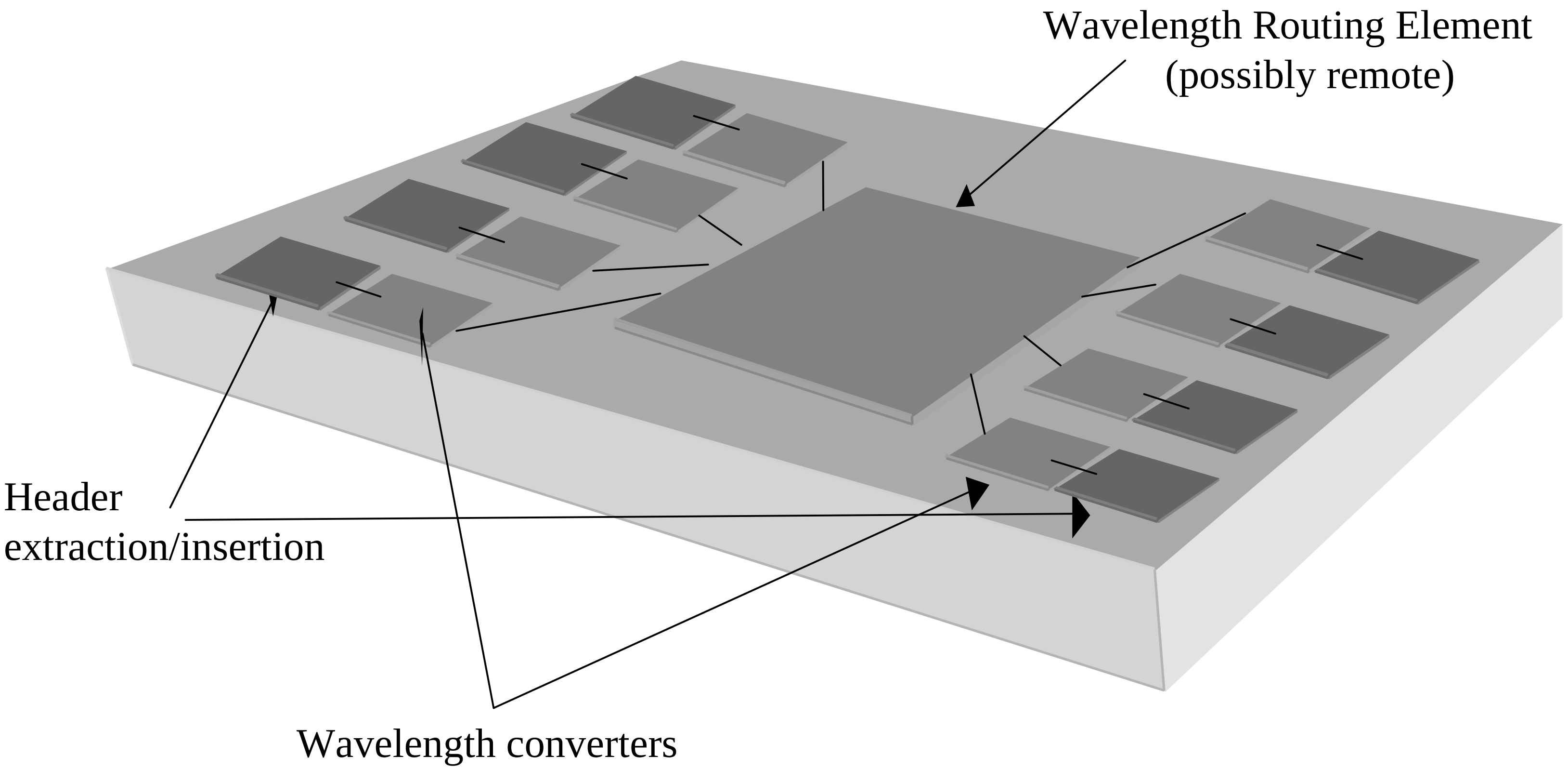
- Optical signal is converted to an electrical signal, then retransmitted
- Large tunability and conversion range
- Much smaller device
- very flexible

Perspective view of O/E/O wavelength converter.



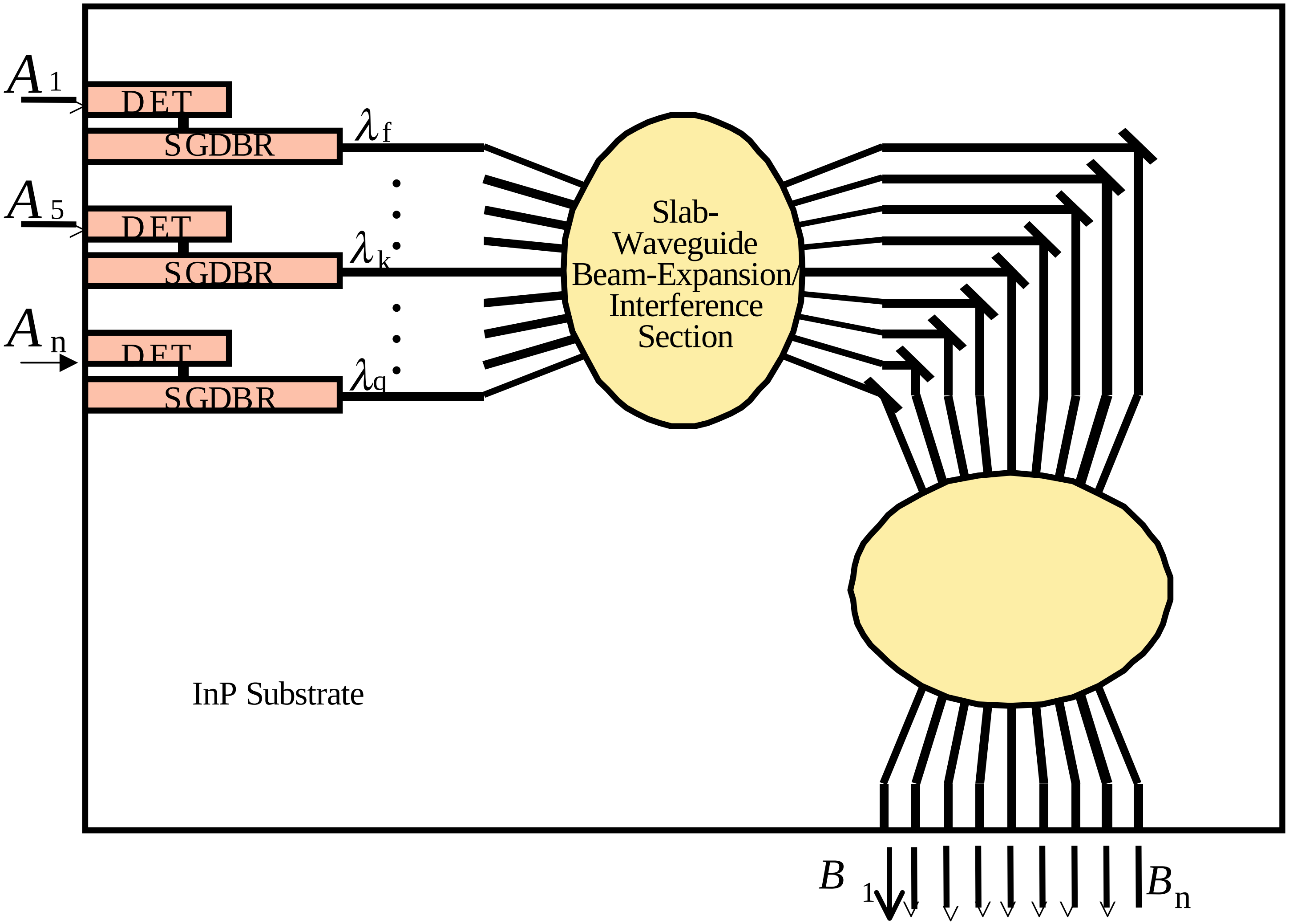
(Much simpler versions are possible by eliminating optional elements such as gratings and preamp in receiver section or an SOA in the transmitter section.)

Optical Switching/Routing



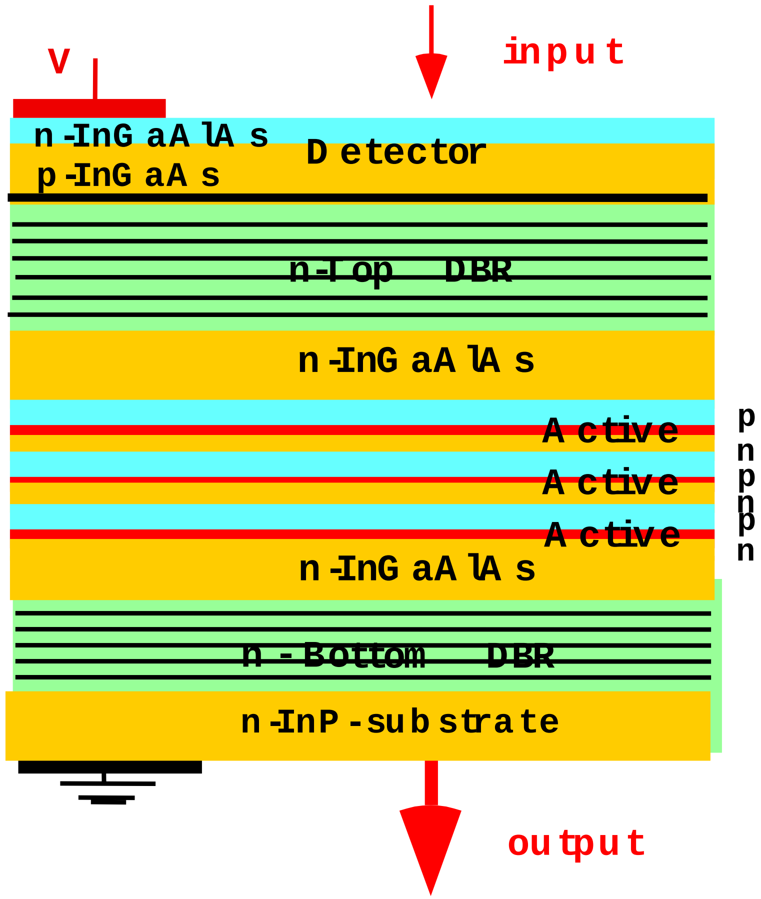
Integration of processing elements and packet switching system on a chip using wavelength routing techniques.

Integrated optical crossbar switch



1-D O/E/O widely-tunable wavelength converter array with a compact AWG. A 32 x 32 switch should fit on a 1 cm^2 chip, assuming 250 μm input & output waveguide spacings.

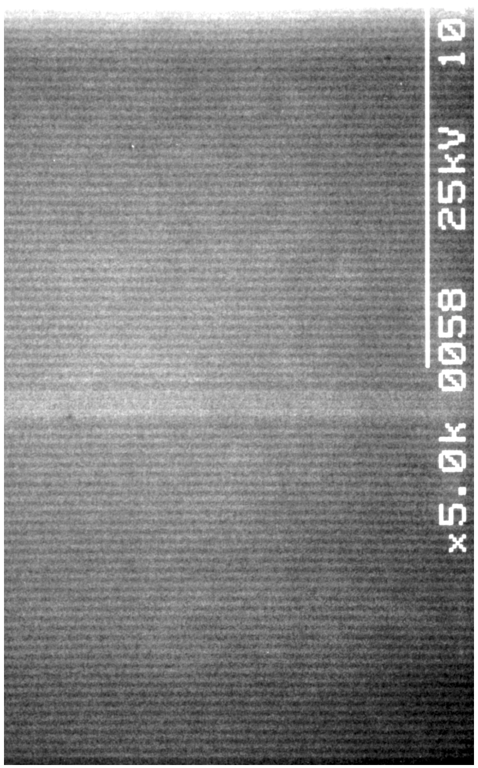
Surface-normal wavelength converter.

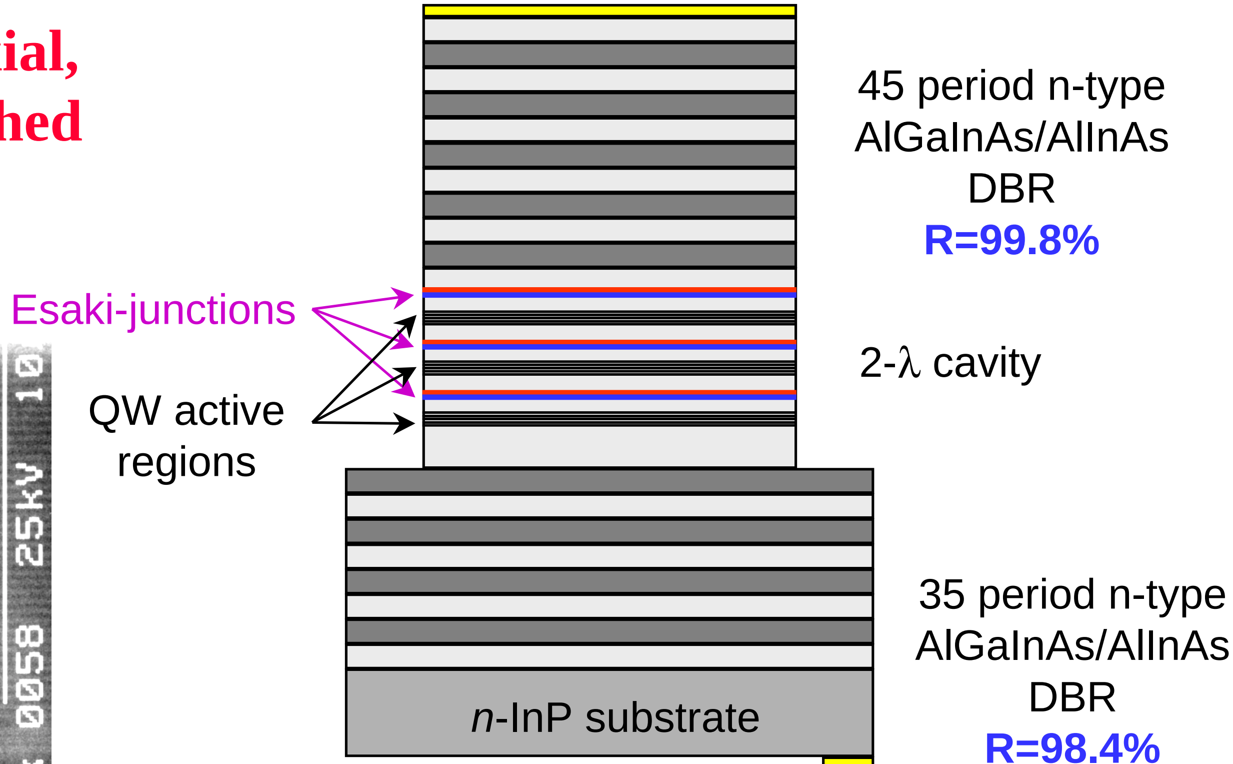


- InP-based VCSEL with multiple-active-regions and series photodetector => PNA

MAR VCSEL

Fully-epitaxial, lattice-matched to InP

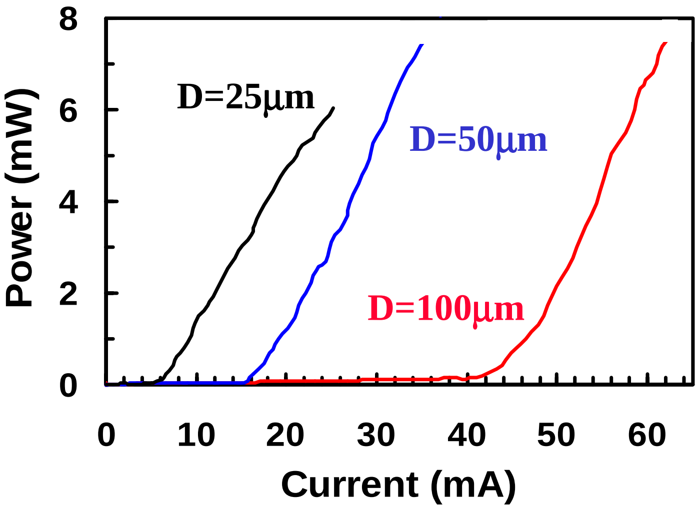




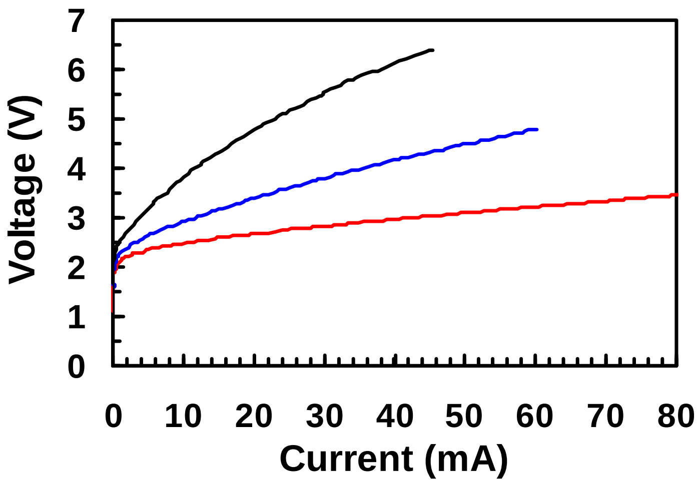
Good quality DBRs

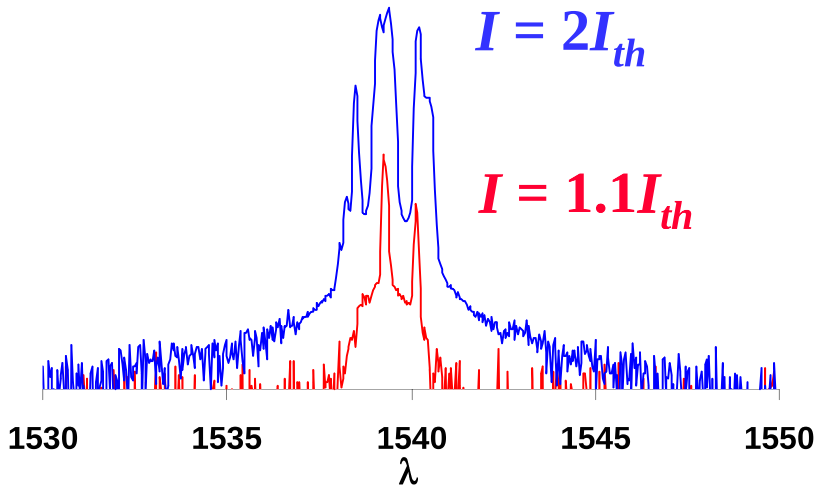
Total thickness of epitaxial layers ~ 20 μm

MAR VCSEL Results

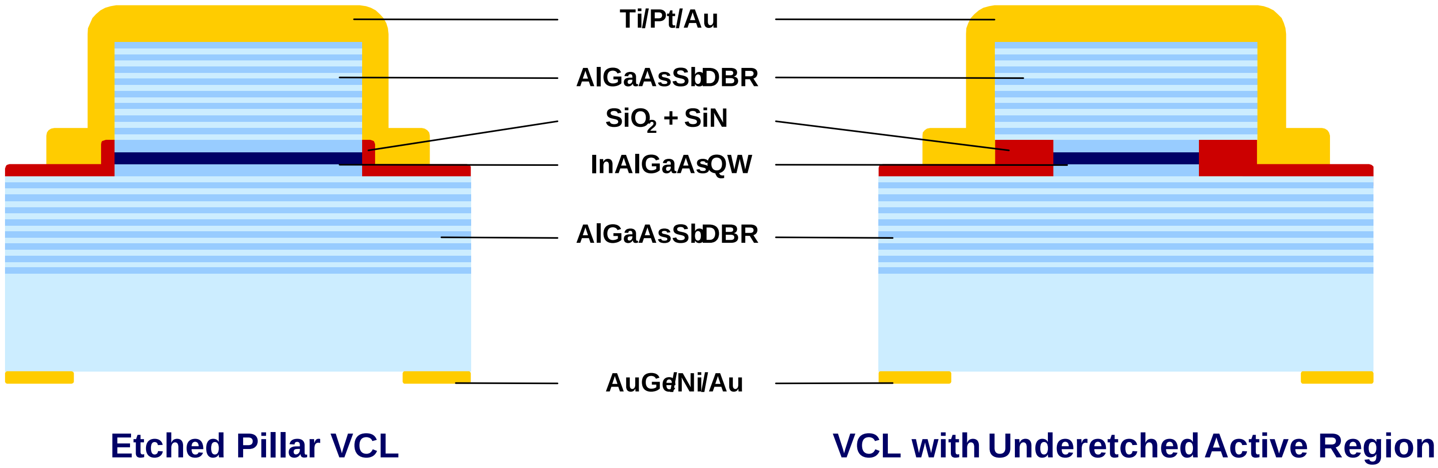


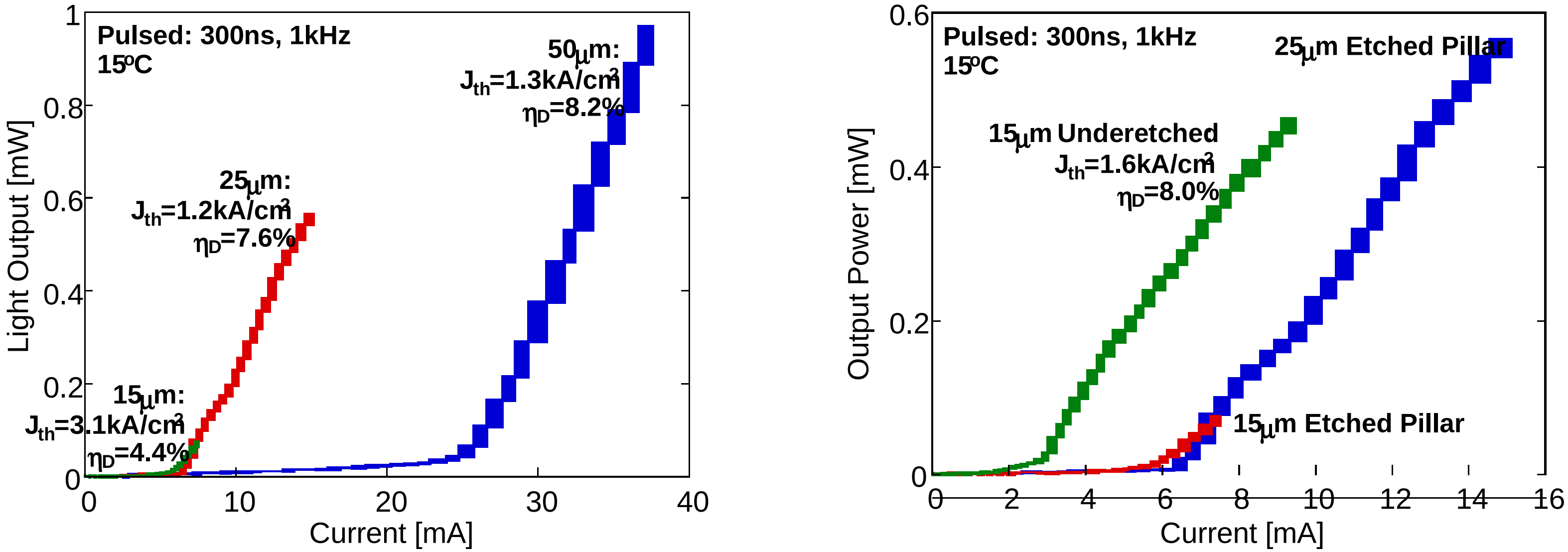
- J_{th} as low as 570 A/cm^2
- $\eta_d > 60$ % (d = 50μm)
- $P_{out} > 15$ mW
- $V_{th} \sim 3$ V ($3h\nu = 2.4$eV)
- $R_d \approx 100\ \Omega$ (d = 25μm)
- $\lambda \approx 1.55$ μm





Sb-Based DBR VCL with Underetched Active Region





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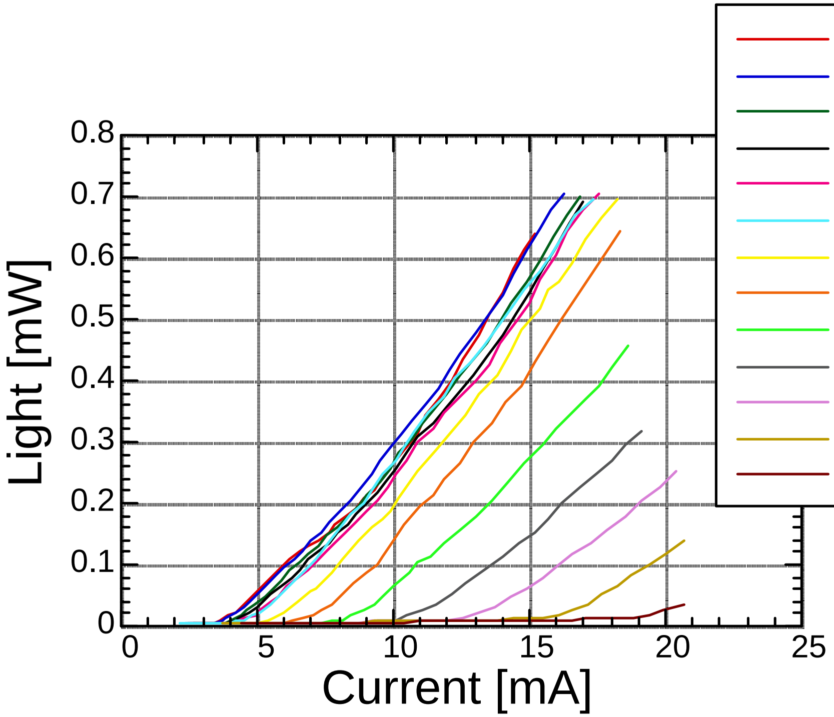
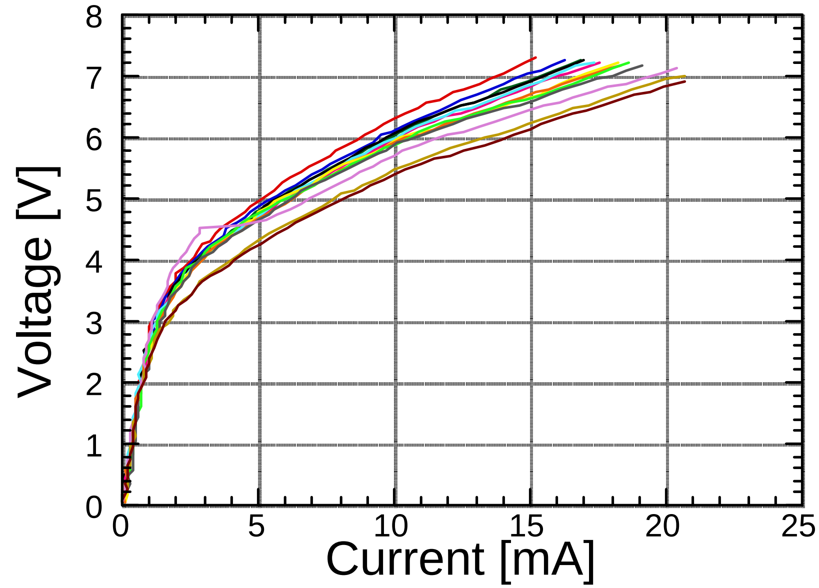
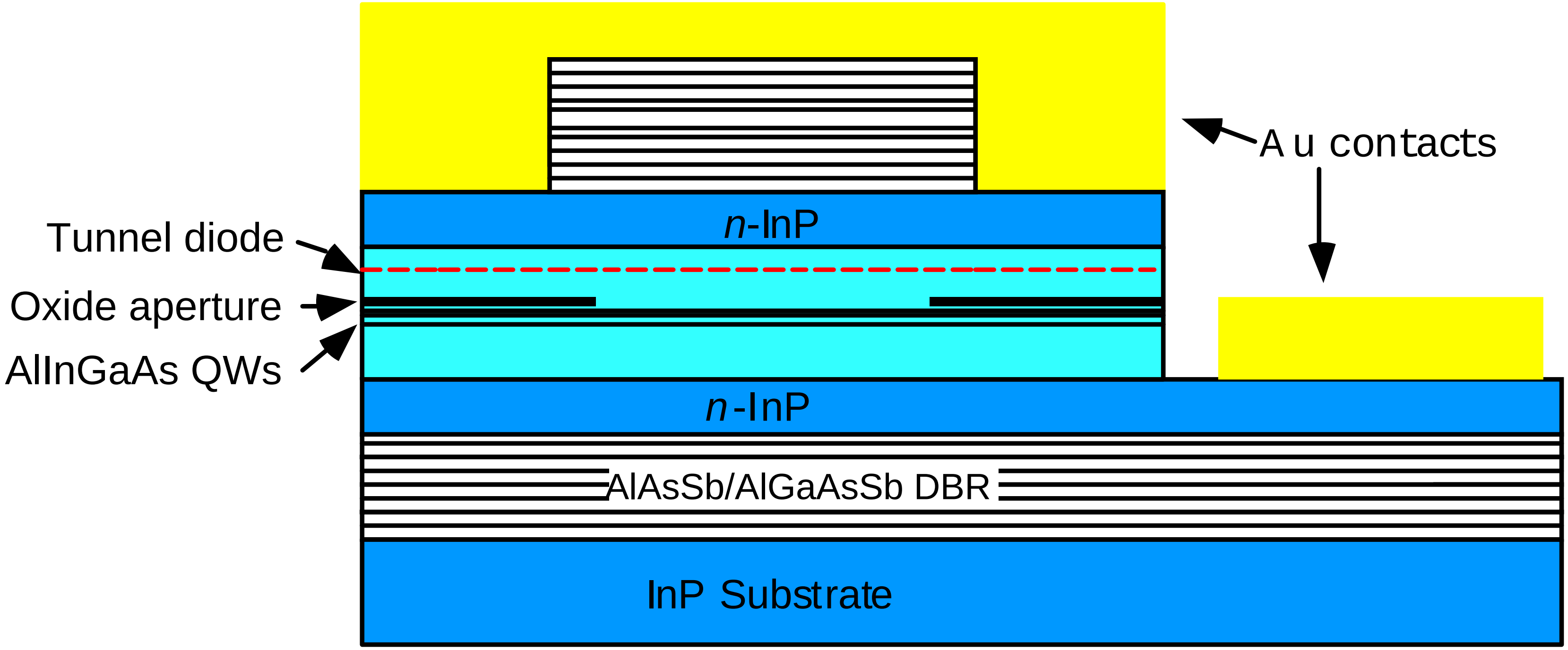
New VCSEL Results





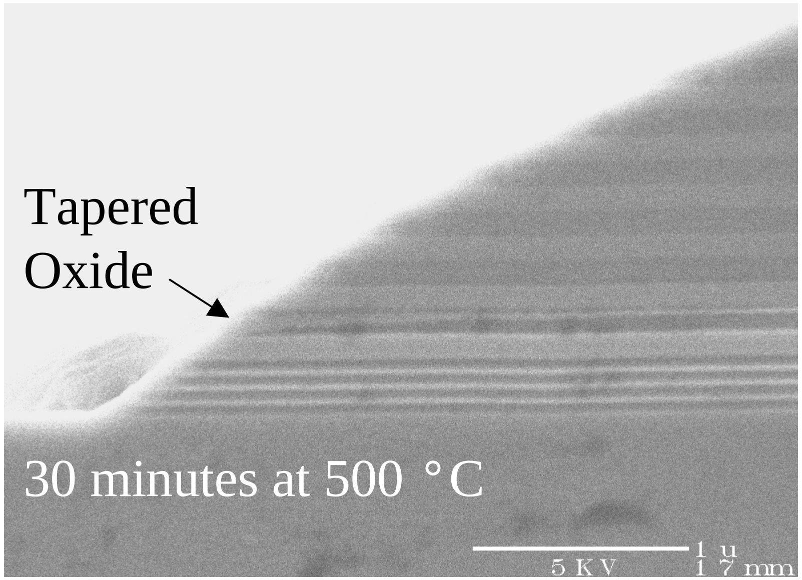
- $\eta_d \sim 7\%$, $J_{th} \sim 800\mathrm{A/cm}^2$
- Voltage reduced by 50% ! !
- CW lasing being tested

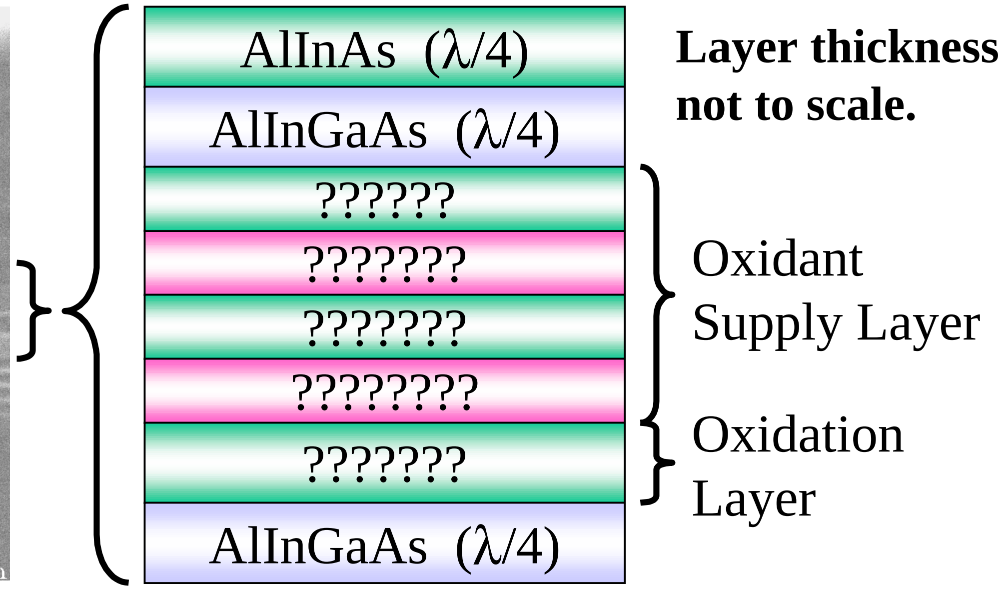
Thermally Managed Long Wavelength VCSEL

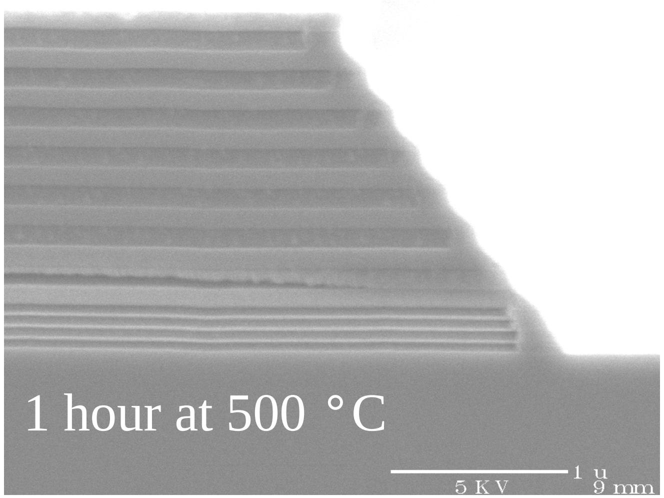


Intracavity-contacted all-epitaxial device with no mirror doping and InP heat spreaders

Tapered Oxide Apertures in AlInAs on InP





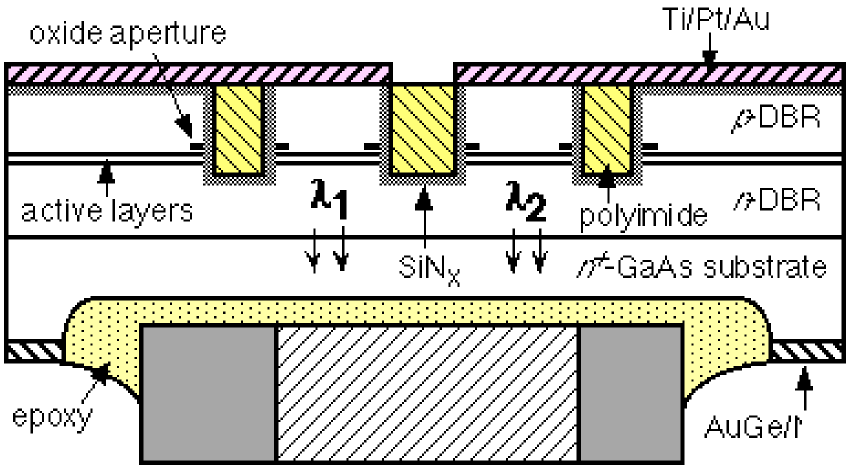


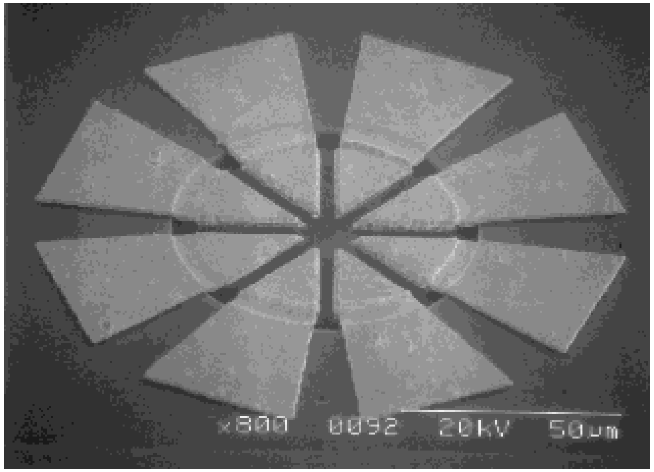
The presence of the oxidant supply layer accelerated the lateral oxidation rate of the neighboring ?????? layer by a factor of 4 relative to identical AlInAs layers elsewhere in the structure.

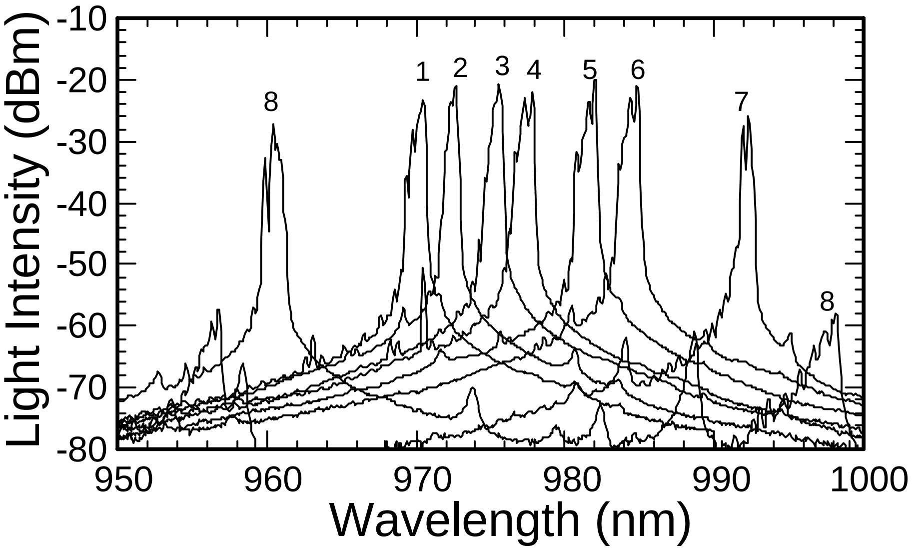
Vertical oxidation of ?????? (oxidation downward from the oxidant supply layer) resulted in a taper.

BOTTOM-EMITTING PIE-VCSEL

S. Y. Hu, et al.,"Multimode WDM opti







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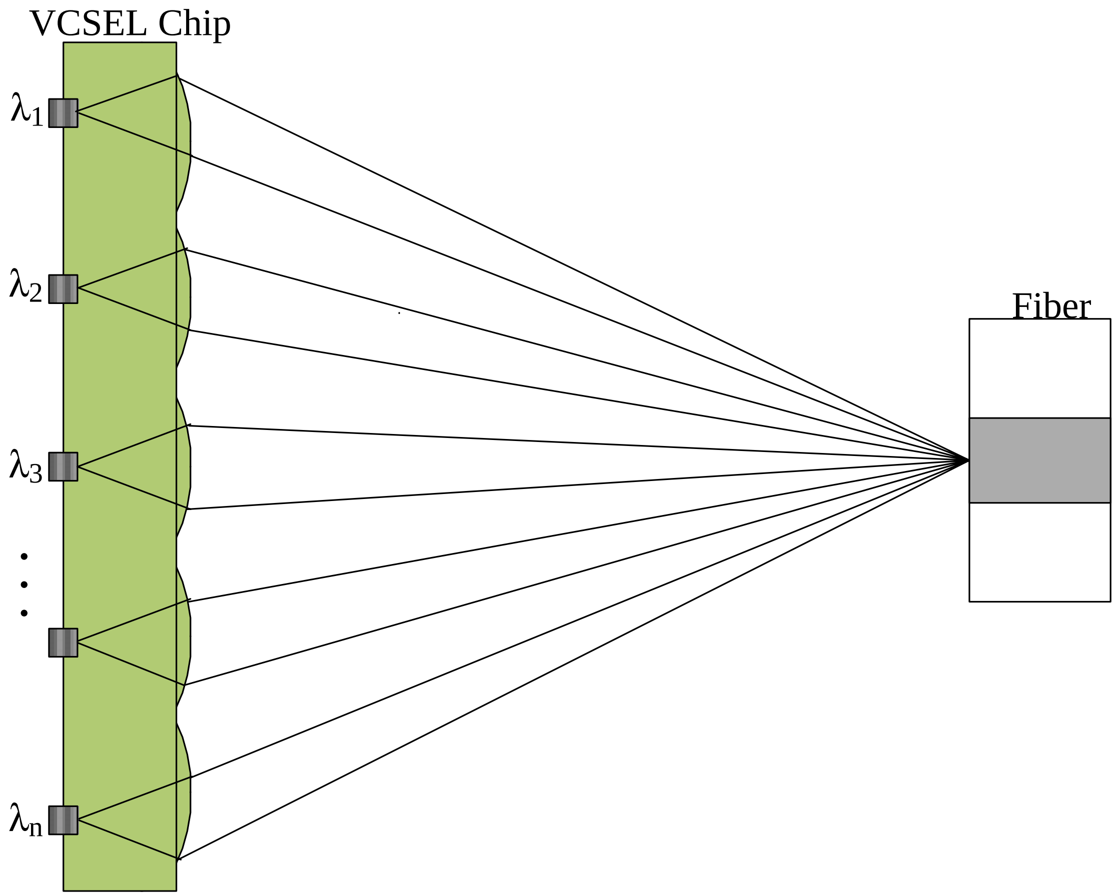
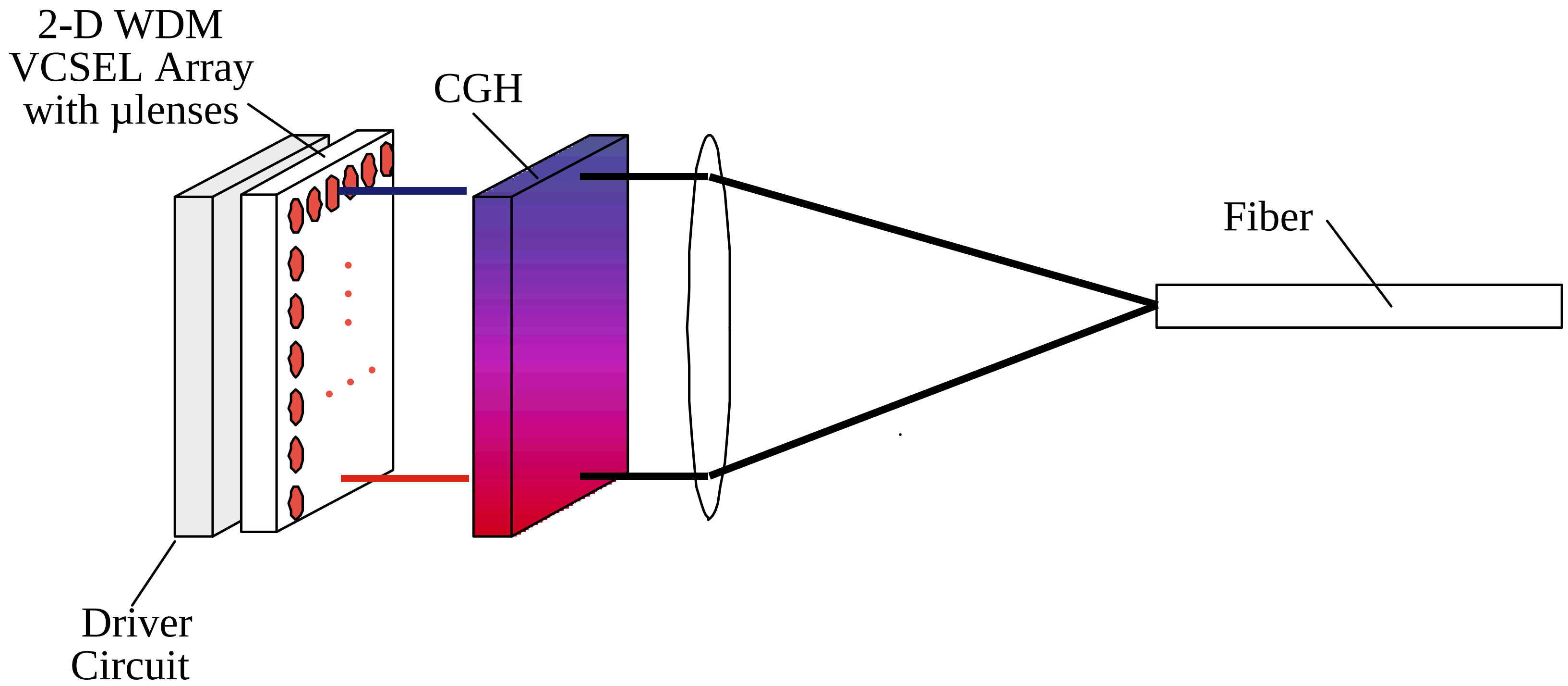
Coupling of WDM VCSEL Array to Fiber



Coupling of several VCSELs to the same point by offset integrated microlenses.
Nearly lossless coupling possible for multimode fiber for angles within its NA.

Coupling of WDM VCSEL Array to Fiber



Use of computer generated hologram (or simple grating in one dimension) to provide spectral separation for matching to single mode fiber

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